Production, Operation and Robustness Module

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ABSTRACT: Nowadays, simulation and Life Cycle Cost (LCC) assessment becomes more and more important in shipbuilding industry. In order to survive in the competitive market environment, manufacturers now have to consider reducing the cost of the entire life cycle of a product, called LCC. This research was initiated with the idea of developing a methodology/framework to be able to assess the life cycle cost/earning of production and maintenance/repair with respect to the scantlings structural optimization variables to be used during the conceptual ship design stage. Three main modules as been implemented during this project: A life cycle cost/earning of production and maintenance/repair, a detailed Discrete Event Simulation (DES) for production and scheduling and a design robustness of the structural solution related to various fabrication and operational parameters. These three modules as well as the main results are briefly presented here.

1 INTRODUCTION

In order to improve the design of products and reduce design changes, cost, and time to market, life cycle engineering has emerged as an effective approach to address these issues in today's competitive global market. As over 70% of the total Life Cycle Cost (LCC) of a product is committed at the early design stage, designers can substantially reduce the life cycle cost of products by giving due consideration to the life cycle implications of their design decisions (Seo et al., 2002].

People are always concerned about product cost, which encompasses the entire product life from conception to disposal. Manufacturers usually consider only how to reduce the cost of materials acquisition, production and logistics. In order to survive in the competitive market environment, manufacturers now have to consider reducing the cost of the entire life cycle of a product, called LCC.

1.1 *Goal of the research project*

This research was initiated with the idea of developing a methodology/framework to be able to assess the life cycle cost/earning of production and maintenance/repair with respect to the scantlings structural optimization variables to be used during the conceptual ship design stage. It is a fact that changes in scantlings might have a big cost impact on production and maintenance/repair due to the variation of steel weight and thicknesses. In general, lighter weight and smaller plate thickness may possibly mean less production cost and more extensive steel replacement during the ship life. However, heavier lightship also means heavier displacement and hence a higher fuel cost or smaller deadweight capacity, and hence lower operational income for a bigger production cost.

Present practical applications of the robustness techniques to the large number of industrial cases have proven their usefulness and theoretical critiques have always been balanced with their large practical success. In that respect, designs optimized for robustness is recognized in IMPROVE as practical measure that can save the designer's/yard's effort on control of the parameter variation.

1.2 *Challenges of the research project*

The challenge of the project was to:

- Keep the high performance of the optimisation loop with a very low response time cost calculation module
- Keep sufficient detail in modelling for a good simulation of production problems (sequencing, transport, human resources, space allocation etc.)
- To introduce robustness into design process as practical measure that can save the designer's/yard's effort on control of the parameter variation.

In order to achieve these challenges 3 main modules as been implemented during this project:

- A life cycle cost/earning of production and maintenance/repair
- A detailed Discrete Event Simulation (DES) for production and scheduling
- A design robustness of the structural solution related to various fabrication and operational parameters

2 LIFE CYCLE ASSESSMENT

2.1 *Introduction*

Design improvement in such a way that maintenance is easier and that ship problems are less frequent or less important may certainly reduce the cost of exploitation and increase safety. Currently, the LCC is not yet a major issue of the shipyards. This is an economic and strategic mistake. Integration of the LCC including maintenance and operating costs in the design procedure could be used by designer and shipyards as a huge selling argument. If the shipyard can show to the ship-owner that the proposed design satisfies the standard technical requirements and the usual ship-owner specifications but also considers maintenance and operation issues, the shipyard may get order even if its offer is not the cheapest. Ship-owners want to minimize short term investment but above all maximize their benefits.

The primary objective of the design effort, besides creating the information needed to build the ship, is to satisfy the ship owner requirements at minimum cost. An owner requires a ship which will give him the best possible returns for his initial investment and running costs (Eyres, 2001). Life cycle costs have often been a major consideration for commercial ship owners who must look at the bottom line for profit and a return on their investment. For instance, if the cost of design and production cannot be recoupled within a reasonable amount of time, the ship will not be built. In the same way, if the operating and maintenance costs exceed operating revenues, again the ship will not be built. Design methods for minimizing the life cycle cost of the product thus become very important and valuable.

2.2 *Development of a module*

A life cycle cost module has been implemented. This module contains 5 sub-modules: the production and material cost, the cost of periodic maintenance, the fuel consumption, the operational revenues and the dismantling revenues. A corrosion model according to the new Common Structural Rules (CSR) for tanker ships that modifies the behaviour of the LCC module has also been implemented.

This basic module is able to compute the material cost (as a function of weight), the labour cost and the LCC using a simplified methodology. The advantage of this module is to find a result as fast as possible. This module is already integrated into the design optimization loop of LBR5, OCTOPUS and CONSTRUCT. In order to link the objective function to the design variables, the unitary costs of raw materials, the productivity rates for welding, cutting, assembling must be specified by the user as well as the lightweight and the deadweight of the ship. These unitary costs vary according to the type and the size of the structure, the manufacturing technology (manual welding, robots, etc.), the experience and facilities of the construction site, the country, etc.

2.4 *Results and conclusions*

From the work carried out in this study, the following are main contributions:

- The developed life-cycle maintenance/repair cost model is robust enough to be used within the IMPROVE's integrated search platform. That is to find maintenance/repair related cost/earning values for the Chemical tanker vessel with respect to design of experiments throughout the optimisation
- The developed method can efficiently help designers, ship owners and production engineers to make rational decisions during early design phases
- Although the model is able to calculate generalized life-cycle maintenance cost, it can

also be used for what if scenario analyses with respect to other parameters of the model, such as unit price of steel replacement per kg, price of fuel oil, and so on

- This model can further be improved with the inclusion of other life-cycle cost elements to be able to find the (significant) cost drivers of the vessels

The examination of the effect of additional steel weight on the original design in order to minimize the steel repairs throughout the life cycle of a ship proved to be feasible under certain assumptions.

3 PRODUCTION SIMULATION ASSESSMENT

3.1 *Introduction*

Production simulation or Virtual Manufacturing (VM) enables the modelling and simulation of production systems and processes to ensure, in advance of the start of production, that they operate at peak efficiency. Simulation is a key new technology of the millennium with considerable expected growth rates per year (Hübler, 2006, Bair, 2009).

Production simulation is the process of designing a model of a real or imagined product and conducting experiments with that model. The purpose of simulation experiments is to understand the behaviour of the product and to evaluate strategies for the production/operation of the product.

Discrete Event Simulation (DES) programs like Plant Simulation from Siemens solution allows the mobilization of virtual plant like shipyards where product data contains all geometrical and methodical information about the ship while the simulation model includes all parameters describing the production facilities, resources (machines, humans, etc.) and processes. One of the major advantages of the production simulation is that it is possible to integrate the operating rules of each workshop and simulate the complex interactions between the different actors (human and material resources, transportation, machinery and tools, etc.). The production simulation is particularly effective to tackle phenomena such as the surface management, transport management, flow management (identification of bottlenecks), management of failures and hazards, etc. that a simple analytic workload simulation cannot integrate.

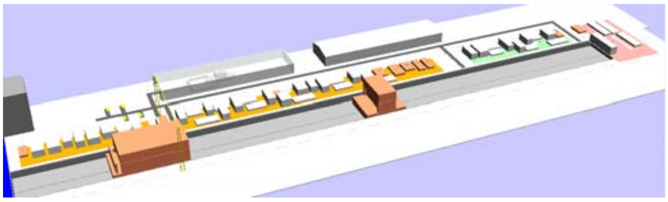
The cost assessment of a product starting from simulation model is a quite easy task. Indeed, all individual process times of the manufacturing tasks are a result of the simulation and linked to various resources. To assess the cost of the process, we can just multiply the operating time of each resource by his dedicated cost rate (Euros/hour).

3.2 *Development of a module*

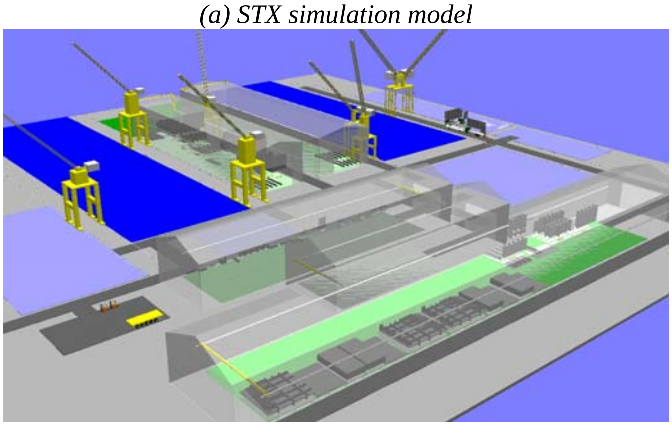
The second assessment method based on a detailed production simulation validated and improved the first LCC assessment mentioned above. The advantage of this module is to find a more accurate result than the previous one. Therefore, due to the need for more detailed input data, time consumption and the high number of constraints and interdependencies considered, this module have been implemented outside of the design optimization loop. The results are lead time and a manufacturing cost with a high degree of accuracy.

This module has been developed following 3 stages:

1. The implementation of simulation database supporting data for the cost and budget calculation as well as for the simulation process.
2. The implementation of budget assessment module based on all welding data as the welding length, welding position as well as the welding throat or the plate thickness.
3. The implementation of simulation models (AKERYARDS - **Figure 1** (a), ULJANIK - **Figure 1** (b)) based on event oriented simulation for production using the Simulation Toolkit for Shipbuilder developed for Plant Simulation working with high degree of details and accuracy.



(a) STX simulation model



(b) Uljanik simulation model

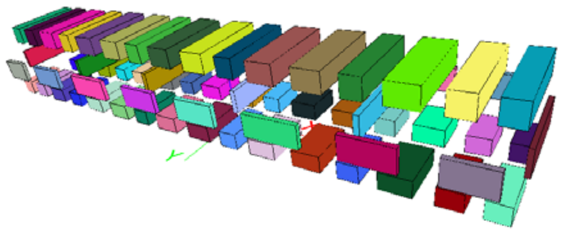
Figure 1 : Production simulation models

3.3 *Results*

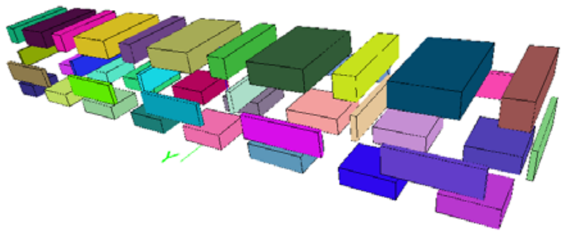
Different ships alternatives have been considered for the both simulation model (STX and Uljanik). And a relative comparison of results between each ship alternative has been performed.

The different ship alternatives for the simulation take into account of the following elements:

- STX model
  - A standard membrane LNG carrier and the innovative concept of a free ballast membrane LNG carrier have been considered.
  - Two blocks and sections splitting have been considered for the production simulation. The first one considering a maximum weight of blocks of 800 tons and a second one with a maximum weight of blocks of 1200 tons (see **Figure 2**).
  - Two states of the scantling have been considered in the production simulation. The first one is the initial scantling provided by the STX shipyard and the second one is the optimized scantling provided after the optimization thanks to LBR5 software.



(a) 800 tons block splitting strategy (#70)



(b) 1200 tons block splitting strategy (#43)

Figure 2 : Block splitting strategies

- Uljanik model
  - A standard design of a Ropax and two new designs regarding the arrangement of internal bulkhead have been considered.
  - Two states of the scantling have been considered in the production simulation. The first one is the initial scantling provided by the Uljanik shipyard and the second one is the optimized scantling provided after the optimization thanks to OCTOPUS software.

The lead time, the production cost (Transport cost + Labour cost + Surface utilization cost) as well as the space allocation and the workload are measured and compared for each ship alternative as the result of the project.

Main trends of the results regarding the STX model are that significant lead time and cost can be save after the scantling optimization of the amidships section of the ship. The main factors acting on the cost reduction is the diminution of the plate thickness as well as the diminution of the stiffener welding length. However, the results shows also that much more can be save if we reorganize or improve also the production process, e.g. another block splitting, sequencing and key resources like cranes.

Similar findings have also been obtained for the Uljanik model. In the same way, the reduction of plate thicknesses and stiffener welding length lead to the diminution of the lead time and cost. Nevertheless, in this model, a key additional point is the limited space for production. We highlighted that the organizational improvements of the allocation of the assemblies may effect heavily the lead time and cost.

3.4 *Conclusion*

The use of simulation-based design and virtual reality technologies facilitates higher efficiency in terms of work strategy planning, and offers, as a result, significant productivity gains.

Different aspects also partially investigated during this project are promising:

- The optimization of the erection sequence
- The combination of production simulation and space allocation optimization (Integration of OptiView and Simulation models)
- The optimization inside of the ship production process using simulation and optimization tools

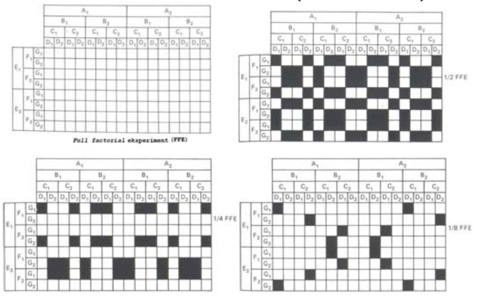
4 DESIGN ROBUSTNESS OF THE STRUCTURAL SOLUTION

Methodology for robustness calculation is based on design of experiments theory. Taguchi's and Suh's measures of robustness have been developed and implemented in the new and fast computational module. The basic theory, descriptions of all developed functions, implementation procedure, worked examples and relevant features of the robustness module are briefly explained in the sequel. Module can be implemented for robustness computation with respect to various structural, fabrication and operational parameters.(Grubisic et al,1997) Identification of the most influential parameters and/or interactions between them can be efficiently investigated.

4.1 *Experimental design*

Statisticians have developed efficient test plans, which are referred to as fractional factorial experiments (FFEs) (Montgomery (1991, Ross, 1988). FFEs use only a portion of the total possible combinations to estimate the main factor effects and some, not all, of the interactions. Simple example is presented in **Table 1**.

Table 1: Reduction of number of experiment for problem with 7 factor on two levels (Ross, 1988)]



4.2 *Robustness measures*

Signal-to-noise ratio (*SNR*) developed by Taguchi is performance measure to choose control levels that best cope with uncertainioty of some factors. The *SNR* takes both the mean and variability into account. In its simplest form, the *SNR* is a ratio of the mean (signal) to the standard deviation (noise). The *SNR* definition depends on the criterion for the quality characteristic to be optimized. While there are many different possible *SNR* definitions, three of them are considered standard and are generally applicable in the following situation:

- Smallest is best quality characteristic
- Nominal is best quality characteristic
- Biggest is best quality characteristic

Among the designs that are equally acceptable, one of these designs may be superior to other in terms of the probability of achieving the design goal (probability of success) as expressed by the criteria requirements. Information Axiom, defined by Suh (Suh, 2001) states that the design with the highest probability of success is the best design.

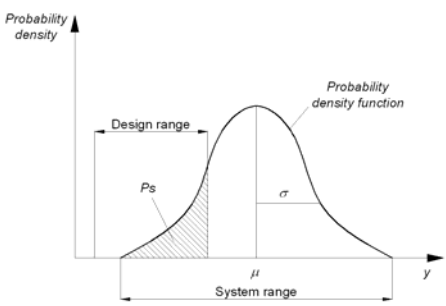


Figure 3: System range, design range and probability of success (Suh, 2001)

The probability of success can be computed by specifying the *design range* and *system range*. **Figure 3** illustrates these two ranges graphically.

4.3 *Practical example*

Example shows the bottom panel robustness calculation for the Ropax ship, using experimental design with the inner array (where user assigns controllable factors) and the outer array (where user assigns uncontrollable-noise factors). For that purpose, four different controllable and noise factors are selected, as follows:

Controllable factors (scantlings)

1) t_p – Thickness of plate, in [*mm*]
2) s – Spacing of ordinary stiffeners, in [*mm*]
3) h_w – Web height of ordinary stiffener, in [*mm*]
4) t_w – Web thickness of ordinary stiffener, in [*mm*]

Noise factors (loads)

1) σ_x – Normal stress in x-direction, in [N/mm^2]
2) σ_y – Normal stress in y-direction, in [N/mm^2]
3) τ – Shear stress, in [N/mm^2]
4) p – Pressure, in [kN/m^2]

For given panel dimensions, scantlings and loads the following feasibility criteria functions set (yield, and buckling criteria) should be satisfied:

1) SYCP – Stiffener Yield Compression Plate
2) SYCF – Stiffener Yield Compression Flange
3) PP_CB – Plane Panel Compression and Bending
4) PP_BACS– Plane Panel Bi-axial Compression and Shear
5) OS_VBM– Ordinary Stiffener Various Buckling Modes
6) OS_US – Ordinary Stiffener Ultimate Strength

Results are presented in **Figure 4** and **Figure 5** where 27 experimental designs (e =1-27)) are sorted according to the volume/weight of material (normalized to the heaviest design e=1). Standard safety measures: deterministic (minimal acheived normalised safety factor – *gmin*, with range -1 to 1) and probability based (probability of success - P_s using CALREL software (Liu et al., 1989)) are presented in **Figure 4.** P_s is normalized to the most safe design. In Figure 5, the most robust designs are identified by maximization of Taguchi's SNR ratio.

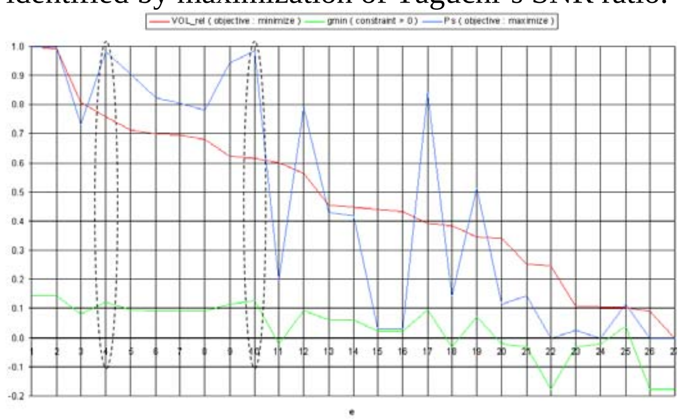


Figure 4: Example results: Deterministic (green line) and Probabilistic safety measures (blue line)-designs are sorted according to Volume (red line)

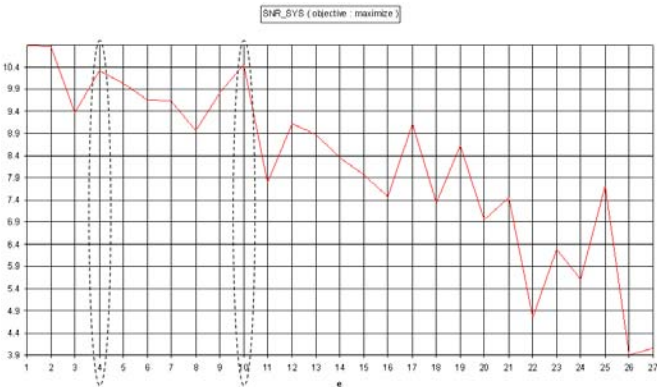


Figure 5: Example results: Robustness according to Taguchi's method

It can be observed that, besides the trivial heaviest designs (e = 1 or 2), the competitive robust designs (e=4, e=10) are identified having considerably smaller volume. Suh's robustness measure gave the same results.

The safety measures used for validation (see **Figure 4**). also have identified those designs as preferred, but not so clearly (*gmin*) or with much more computational effort (P_s).

4.4 Conclusion on robussnes module

Experimentation with robustness attributes is bringing a new dimension to the selection of preferred design, enabling balancing of the original attribute and its (in)sensitivity to uncontrollable parameters. In that respect, design optimization for robustness is recognized in IMPROVE as practical measure that can save the designer's/yard's effort on control of the parameters variation.

It have to be underlined again that robustness measure calculations are much simpler and faster compared to e.g P_s calculations, as described above, and with accuracy acceptable in concept design phase.

5 CONCLUSIONS

The 3 modules implemented during this project:

- the life cycle cost/earning of production and maintenance/repair,
- the detailed Discrete Event Simulation (DES) for production and scheduling,
- and the design robustness of the structural solution related to various fabrication and operational parameters,

helped to support and prove the effectiveness of the three scantling optimization software's (LBR5, OCTOPUS and CONSTRUCT).

The importance of considering simultaneously the LCC, the production aspect and the robustness of the design solutions has been demonstrated in this study.

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